Jet Propulsion Laboratory
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Most Shergottites Were Once Vesicular: Evidence From 3D Computed X-ray Tomography

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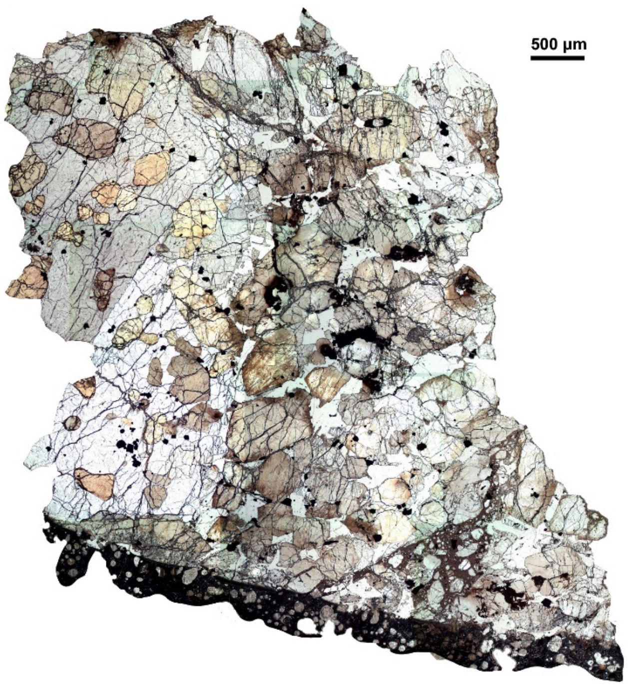
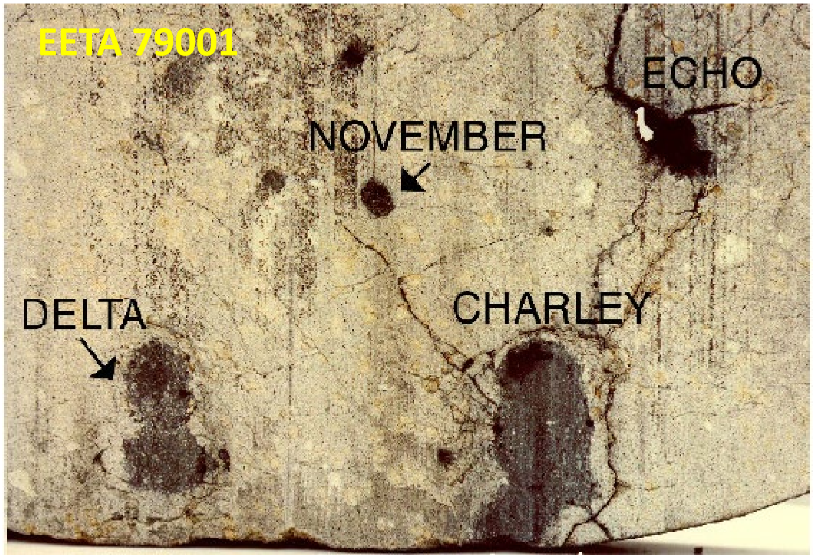
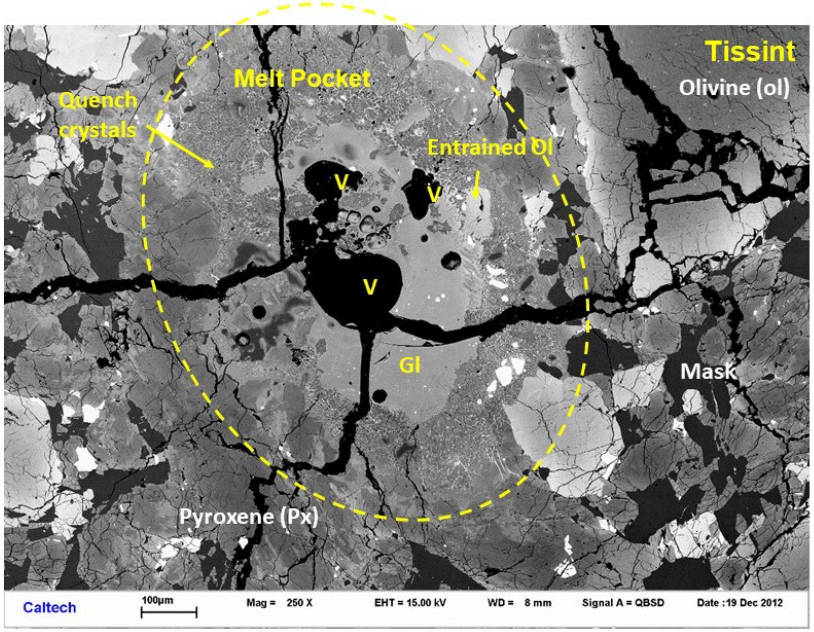
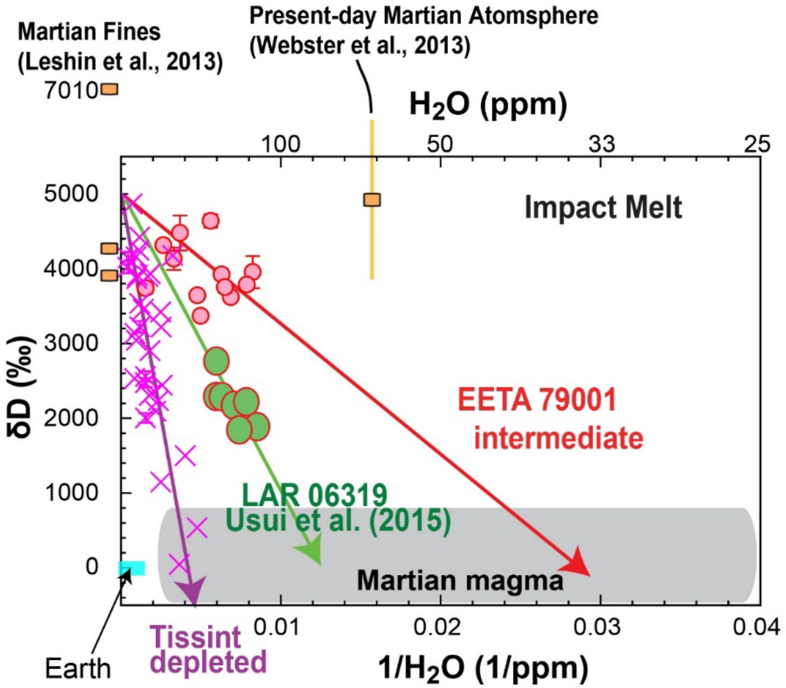
Shergottites

- Mafic meteorites delivered to Earth by impacts on Mars
- Strong shock features, including shock melt pockets
- Volatile-rich shock melt pockets









More volatiles in melt pockets

- H and S contents are most abundant
  - Unlikely to be directly implanted atmosphere by shock (CO2 is often much lower than expected)
- H contents and isotopes require a sub-surface water source
  - Most likely to be (sub)-surface alteration in the vesicles
  - (Sub)-surface fluid carried surface signature (Rao et al. 2018)
- Melt pockets from pre-existing bubbles

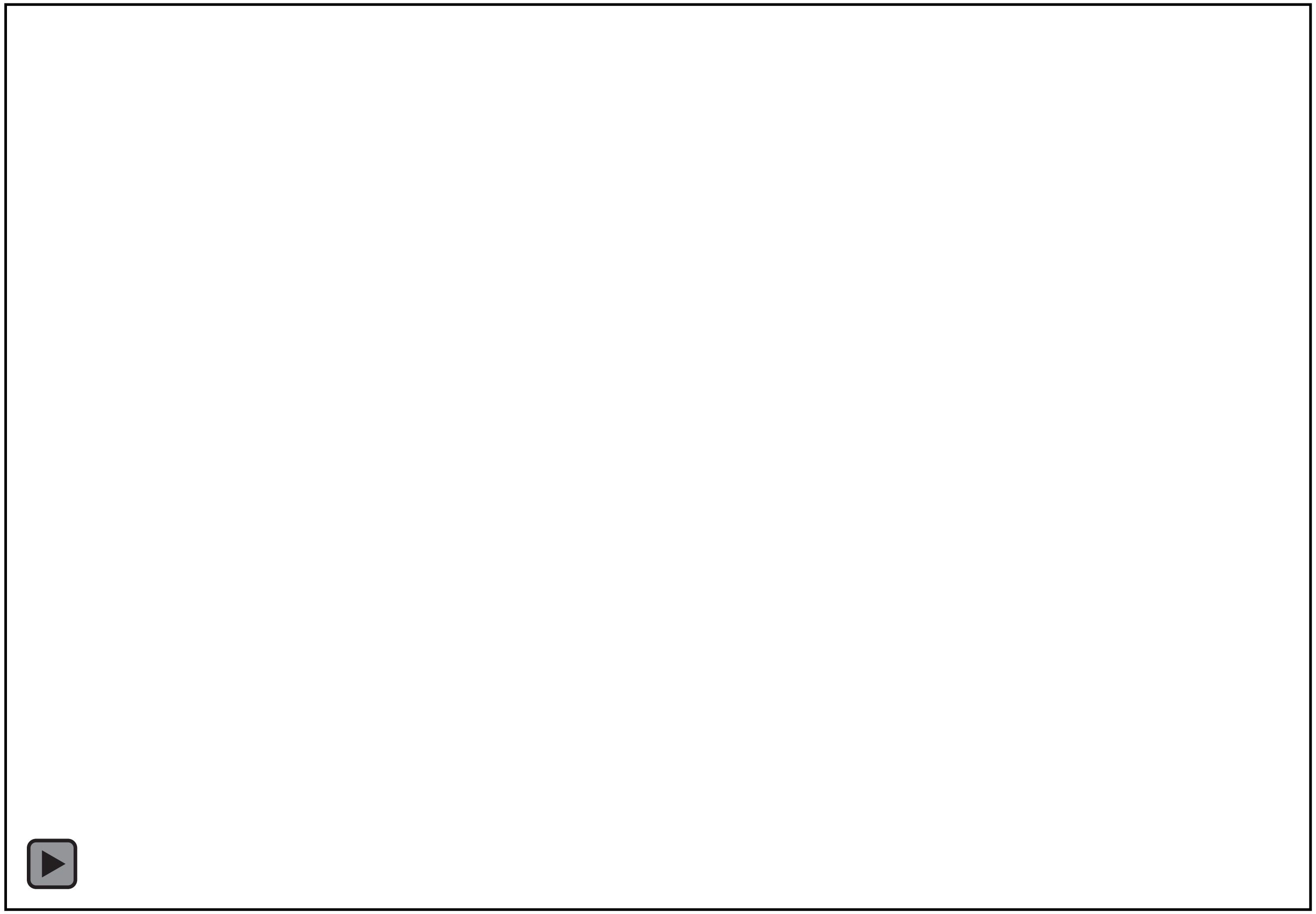
Chen et al., 2015; Liu et al., 2018

Methods

- Fragments of Tissint (10 g), EETA 79001, RBT 04261
- The University of Texas High Resolution X-ray CT facility
- Voxel dimensions are 17.15 microns

Black: light phases (cracks, voids); Dark gray: maskelynite; Gray: Olivine; Bright: dense phases (oxides, sulfides)

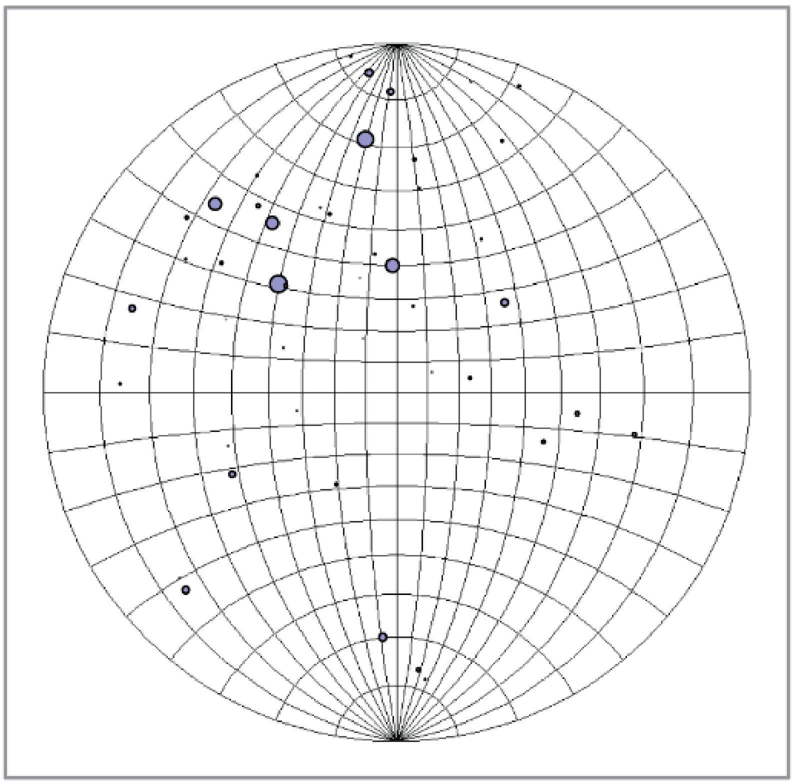
Segmentation

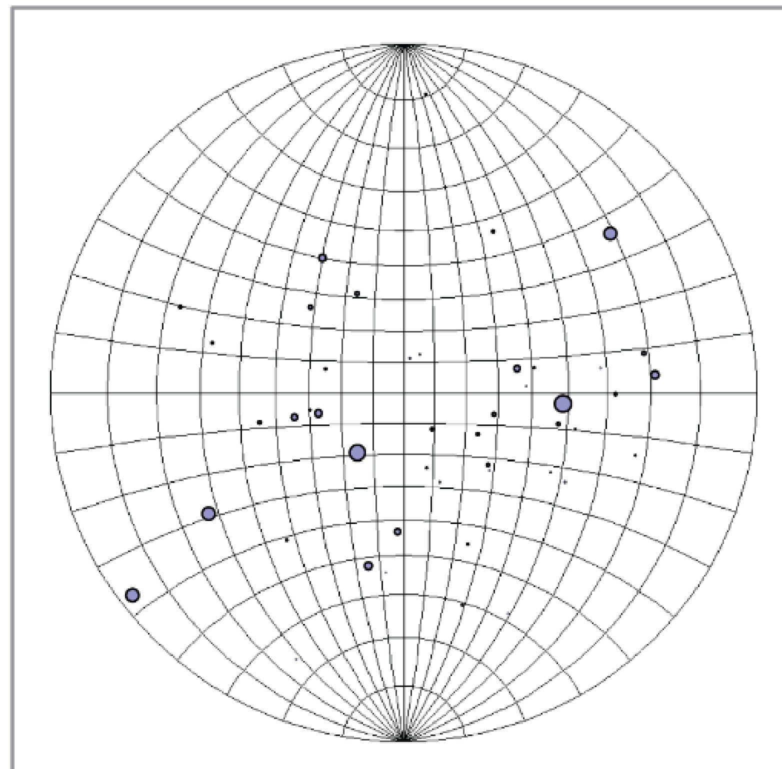


A combination of trainable machine learning techniques and manual segmentation using Dragonfly and Avizo software

Bubbles, melt pockets and fractures

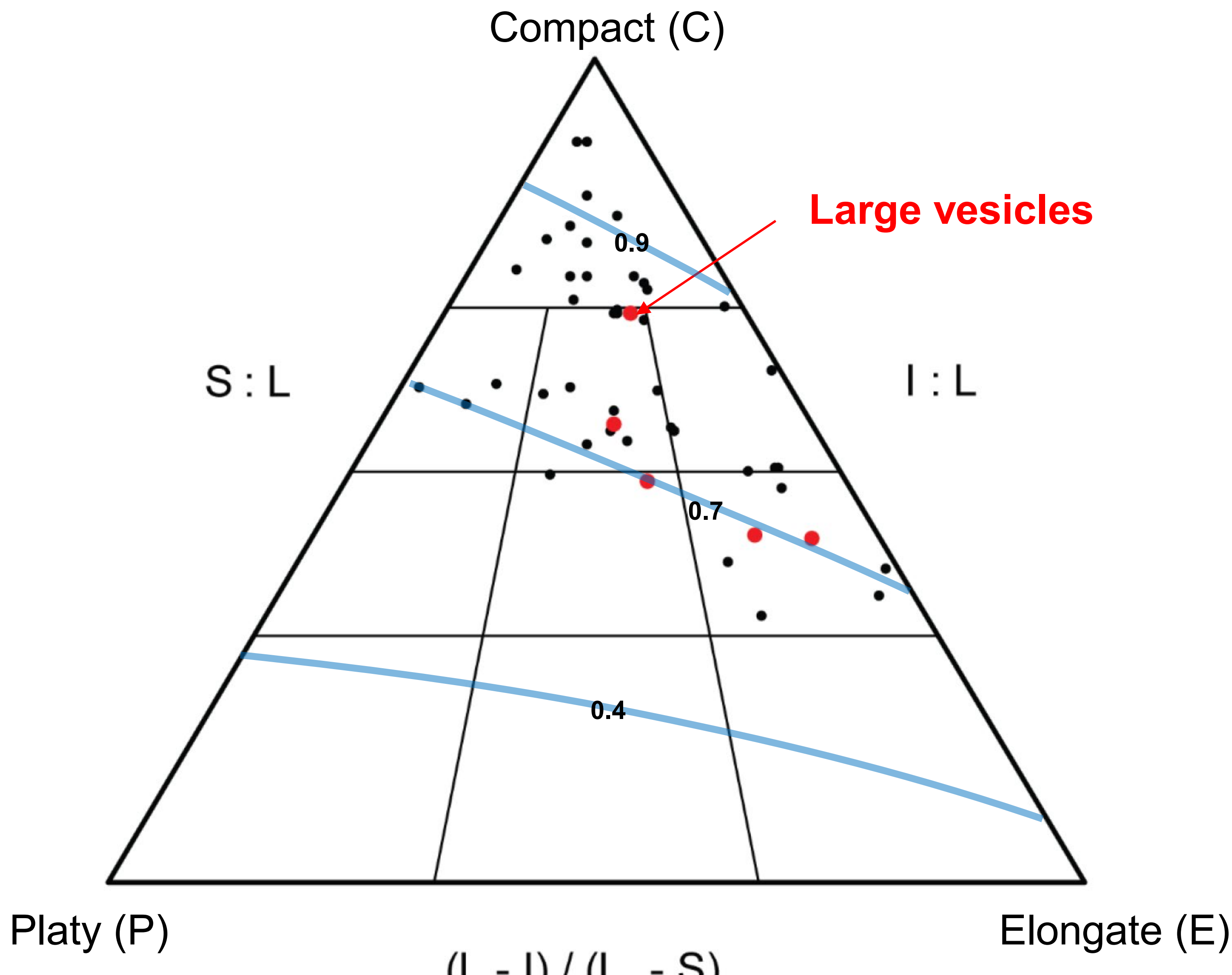
Preferred orientation of large bubbles (long axis >0.5 mm)





Projection to upper hemispheres

About 50% vesicles are irregular and elongated

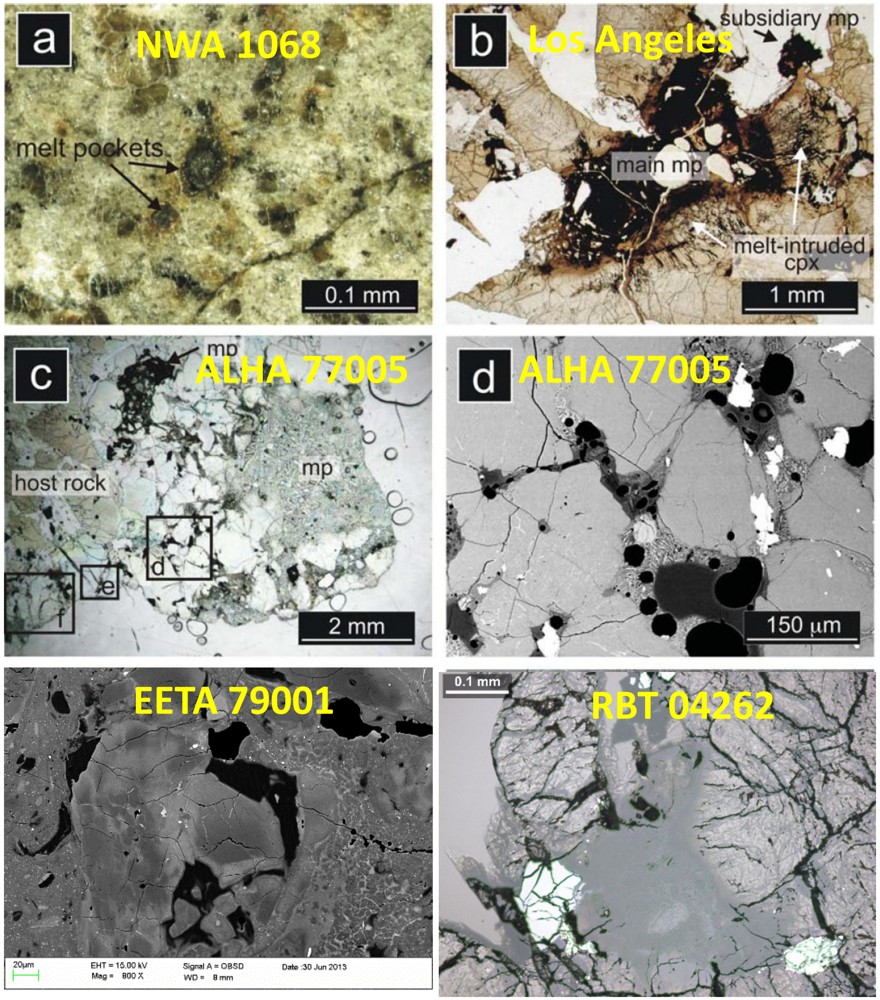


Sneed and Folk classification of grain form

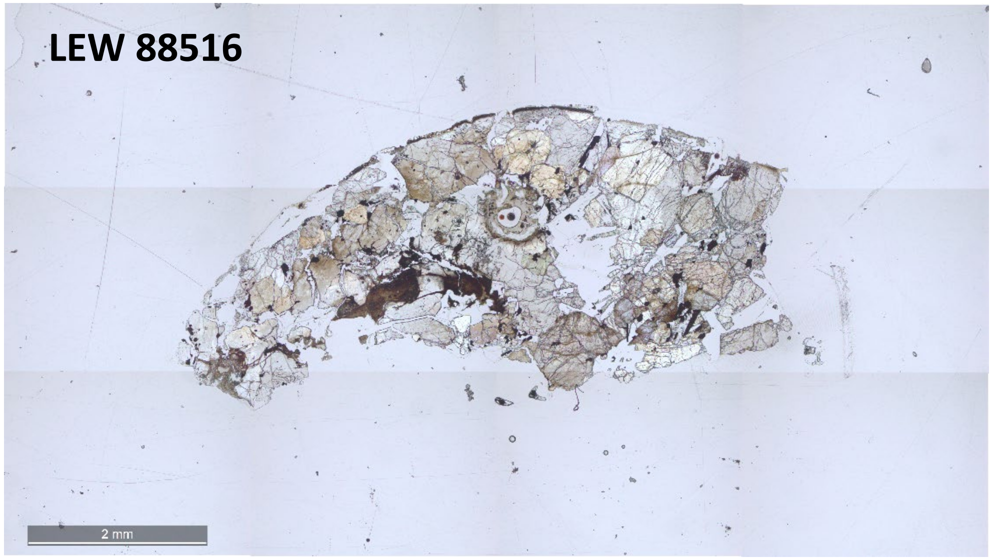
Tissint Results

- Abundant (>35) impact melt pockets with a diameter of >140 µm, randomly distributed in the sample. The largest pocket reaches ~5 mm in diameter.
- Large impact melt pockets contain irregular shaped voids.
- Large bubbles show preferred orientation.
- No melt veins connecting different melt pockets.
- All pockets are associated with clusters of fractures, larger pockets are associated with ring fractures in the rock matrix.
- **Melt pockets formation at the expense of pre-existing vesicles**

Commonality in other shergottites



- Melt pockets in most shergottites contain residual vesicles
- Large-melt-pocket-bearing shergottites were vesicular pre-impact
- Melt pockets contain 100s to 1000s µg/g H_2O



Walton and Spray (2003) Walton and Shaw (2009) Shaw and Walton (2013); and many papers about shergottites

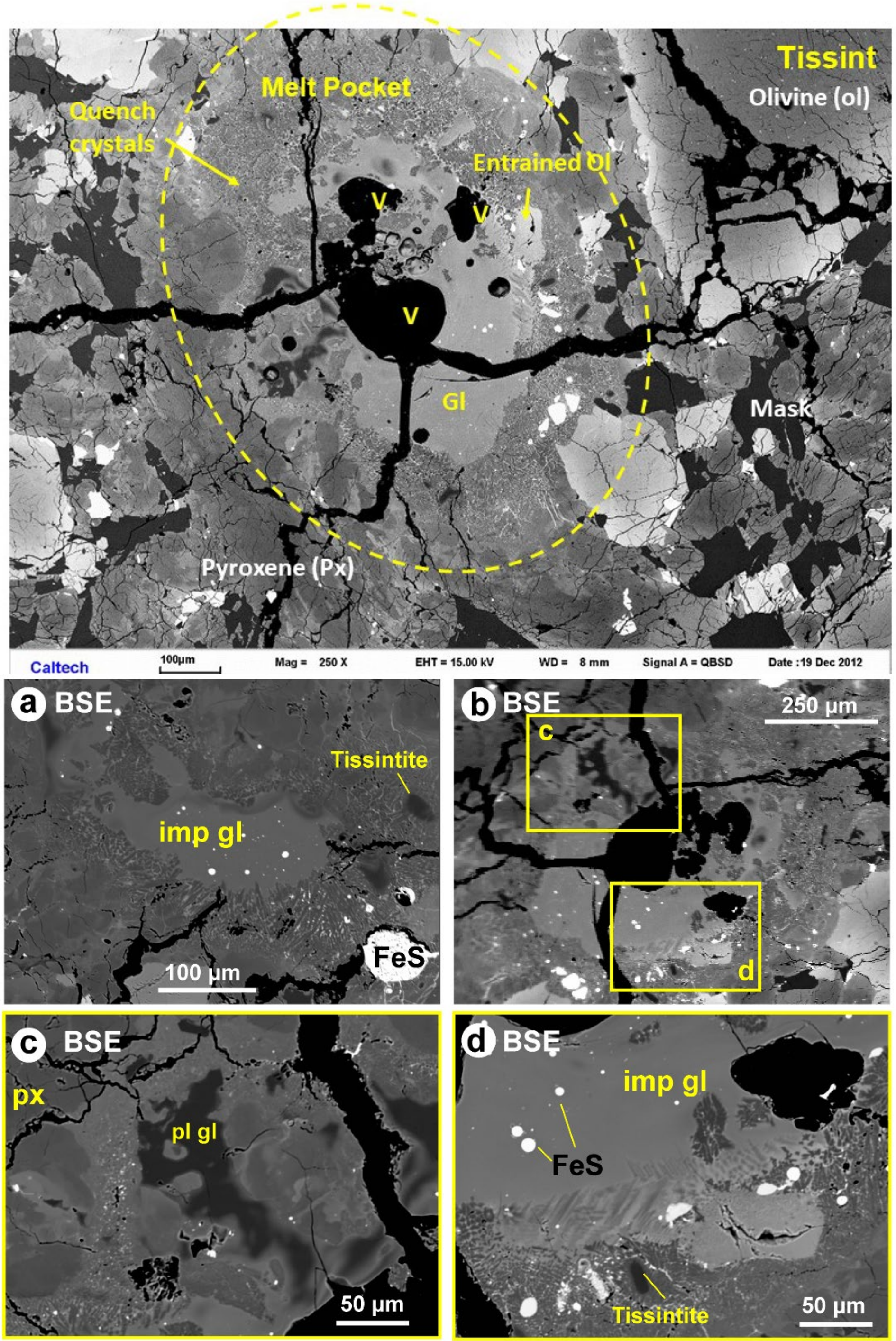
Conclusions

- Interior view of the Tissint meteorite reveal interesting features, offer a dataset for modeling internal melting and thermal effects by shock
- 3D observation and plenty 2D observations of shock-formed melt pockets in shergottites suggest they form around pre-existing vesicles, evidence for significant outgassing during the formation of these basaltic rocks
- Impact melt pockets in Martian meteorites provide the best, if not only, means to study the surface or subsurface fluids at different times and locations, before we can collect, analyze, or return subsurface samples from Mars

Funding sources: the Center for Academic Partnership (CAP) at JPL; NASA

Backup

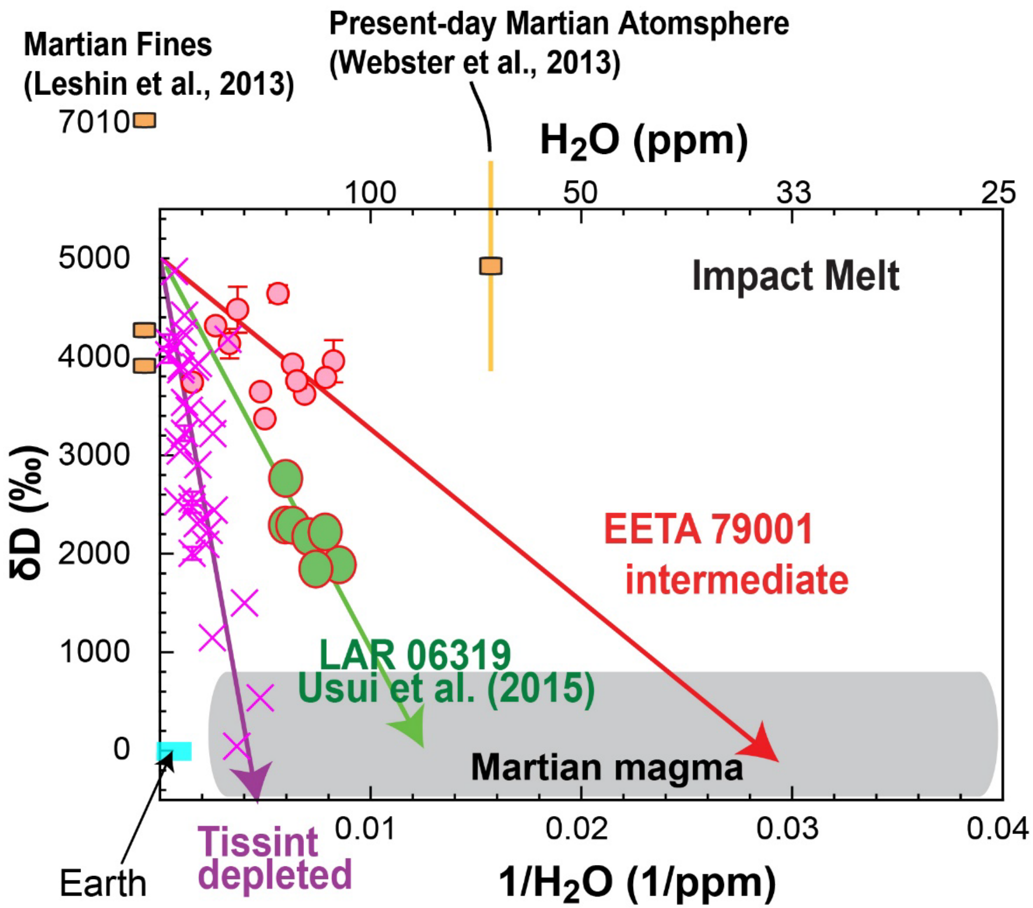
Implications 1: Formation



- Large impact melt pockets formed by *in situ* melting around pore space
- Irregular voids = residual vesicles from incomplete compression
- Smaller pockets <140 μm by density contrasts at grain boundaries

Chen et al. (2015, EPSL); Ma et al. (2015, EPSL & 2016, GCA); Liu et al. (2016, MAPs)

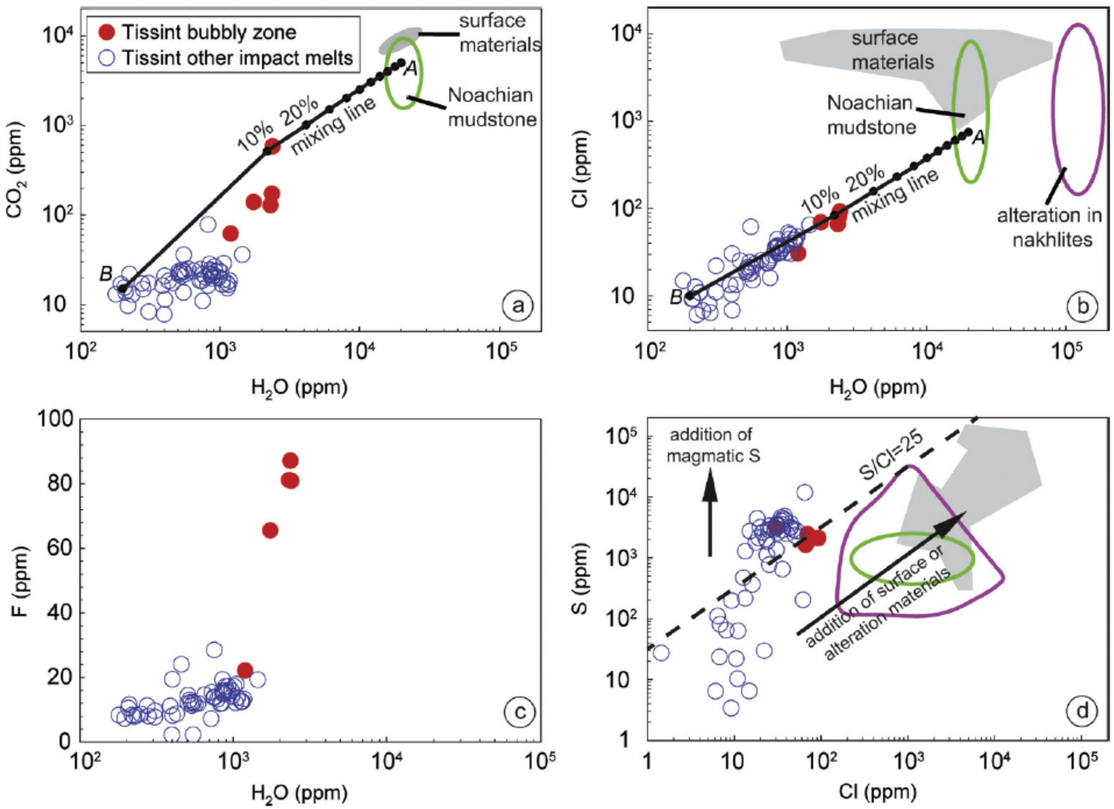
Implications 2: Impact melt pockets as a hygrometer to measure Mars (sub)surface water



Liu et al. (2018 EPSL)

- Sub-surface source
  - Unlikely to be directly implanted atmosphere by shock (CO2 is often too low)
  - Unlikely to be soil injection (no melt veins connecting the pockets)
  - Most likely to be (sub)-surface alteration in the vesicles
  - (Sub)-surface fluid carried surface signature (Rao et al. 2018)

Implications 3: Impact melt pockets as a hygrometer to measure Mars (sub)surface water



Chen et al. (2015 EPSL)

- Melt pockets are volatile rich:
  - 100s to 1000s ppm H2O, S
  - 10s to 100s ppm CO2
  - up to 100 ppm F, Cl
  - >> noble gas contents
- Volatiles form mixing trend between magmatic and (sub)-surface water sources
- Martian meteorites derived from >1 m depth